Poll Everywhere

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Name a *value* that you feel is embedded in the C language.

(open-ended survey question)

By "value" we mean an adjective describing the relative worth, merit, or importance of something (*e.g.*, loyalty, kindess), NOT a number or constant.

CSE333 Systems Programming
Makefiles

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Administrivia

- No more leniency with assignment submission – messed up tag or file locations = no submission
- Exercise 4 ongoing, due on Monday
  - Refer to section materials about how to deal with directories
- ~~Homework 1 due last night (4/16)~~
  - Lol attu went down last night
  - **HW1 due date pushed later by 24hr (tonight, 4/17 at 11:59p)**
- Homework 2 out today
  - Builds on top of Homework 1 data structures to create search engine!

Lecture Outline

- **Make and Build Tools**
- Makefile Basics

make

- make was the first coordinate software **build system** – a program for controlling what gets (re)compiled and how
  - Many other such programs now exist (*e.g.*, `ant`, `maven`, IDE "projects")
  - But make is the OG and still in heavy use today

- make has tons of fancy features, but only two basic ideas:
  1) Be a **centralized space** that holds the commands used to compile our project
  2) Express **dependencies** for those commands so they only run when the source code they process changes (avoid unnecessary work)

- To avoid "just teaching make features" (boring and narrow), let's focus more on the concepts…

Building Software (1/2)

- Programmers spend a lot of time "building"
  - Creating programs from source code
  - Both programs that they write and other people write

https://xkcd.com/303/

Building Software (2/2)

- Programmers spend a lot of time "building"
  - Creating programs from source code
  - Both programs that they write and other people write

- Programmers like to automate repetitive tasks
  - Repetitive: gcc -Wall -g -std=c17 -o widget foo.c bar.c baz.c
    - Retype this every time: 
    - Use up-arrow or history:  (still retype after logout)
    - Have an alias or bash script: 
    - Have a Makefile:  (you're ahead of us)

"Real" Build Process

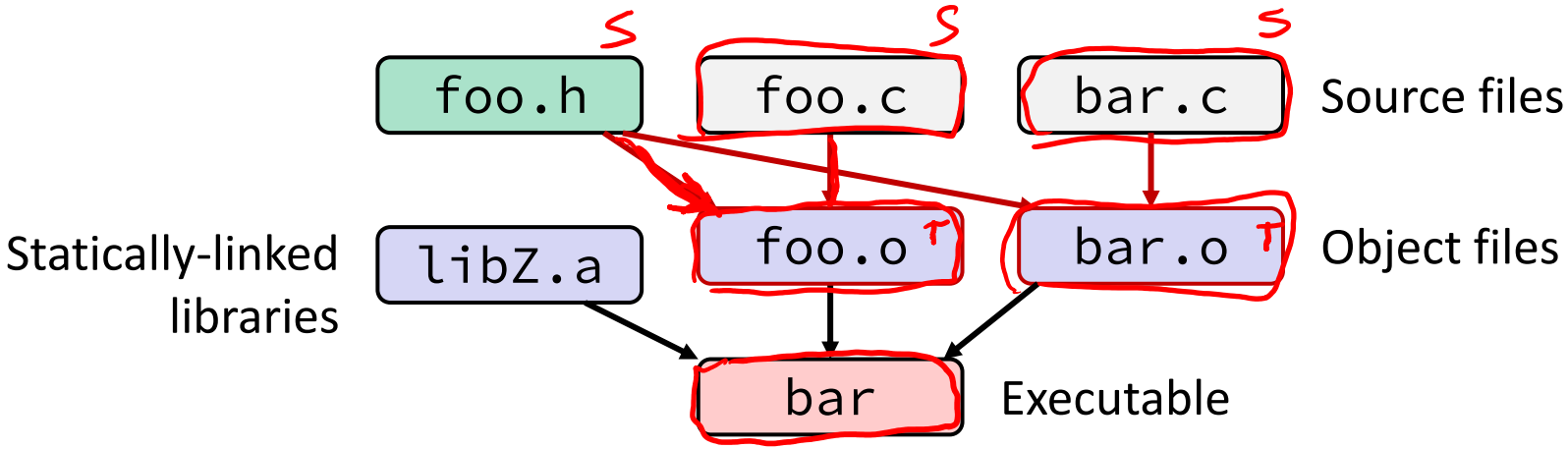
- On larger projects, you can't or don't want to have one big (set of) command(s) that are all run every time you change anything. To do things "smarter," consider:
  1) It could be worse: If `gcc` didn't combine steps for you, you'd need to preprocess, compile, and link on your own (along with anything you used to generate the C files)
  2) Source files could have multiple outputs (*e.g.*, `javadoc`). You may have to type out the source file name(s) multiple times
  3) You don't want to have to document the build logic when you distribute source code; make it relatively simple for others to build
  4) You don't want to recompile everything every time you change something (especially if you have 10^5-10^7 files of source code)
- A traditional shell script can handle 1-3 (use a variable for filenames for 2), but 4 is trickier

Recompilation Management

- The "theory" behind avoiding unnecessary compilation is a *dependency dag* (**d**irected, **a**cyclic **g**raph)

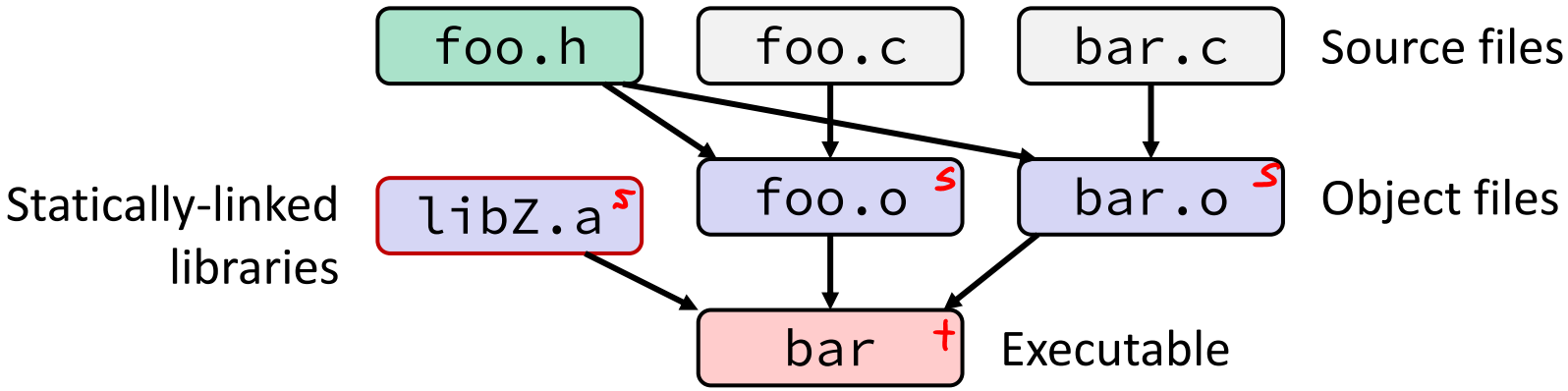
- To create a target t, you need sources $s_1, s_2, \ldots, s_n$ and a command c that directly or indirectly uses the sources
  - If t is newer than every source (file-modification times), assume there is no reason to rebuild it
  - Recursive building: if some source s_i is itself a target for some other sources, see if it needs to be rebuilt…
  - Cycles "make no sense"!

Theory Applied to C (1/4)



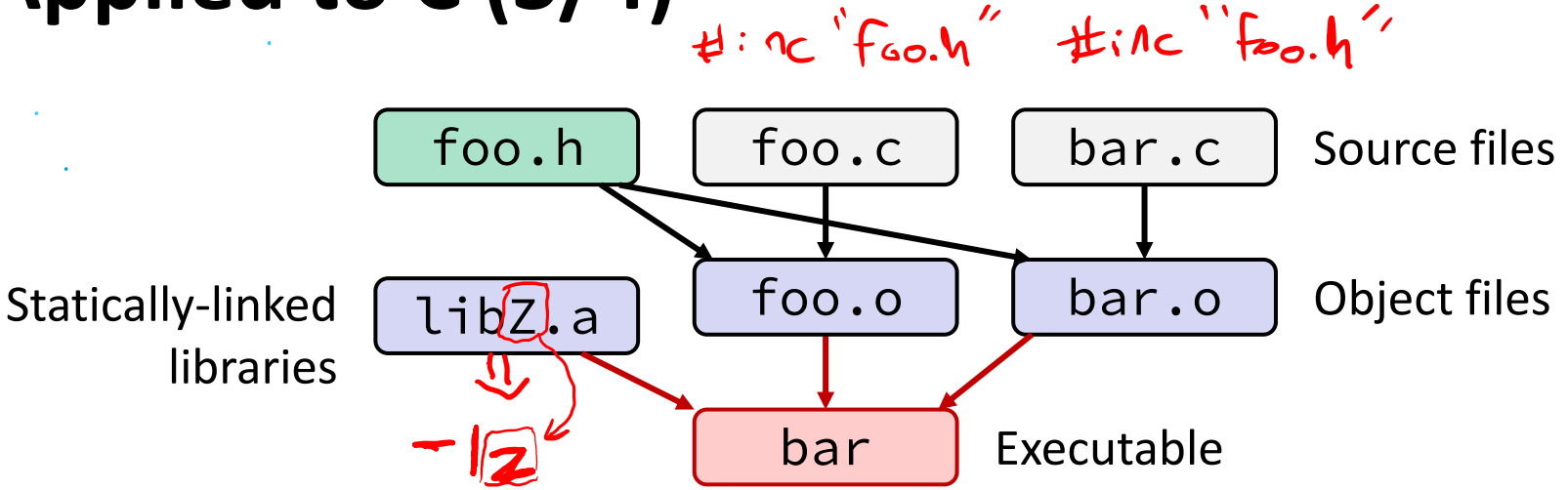
- Compiling a `.c` creates a `.o` – the `.o` depends on the `.c` and all included files (`.h`, recursively/transitively)

Theory Applied to C (2/4)



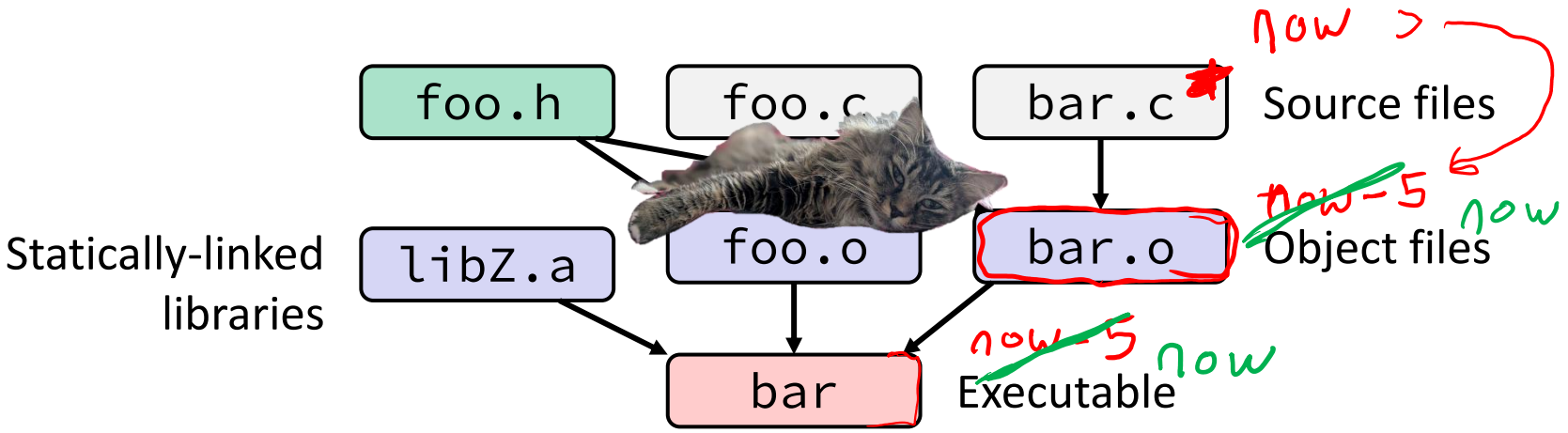
- Compiling a `.c` creates a `.o` – the `.o` depends on the `.c` and all included files (`.h`, recursively/transitively)
- An archive (library, `.a`) depends on included `.o` files

Theory Applied to C (3/4)



- Compiling a `.c` creates a `.o` – the `.o` depends on the `.c` and all included files (`.h`, recursively/transitively)
- An archive (library, `.a`) depends on included `.o` files
- Creating an executable ("linking") depends on `.o` files and archives
  - Archives linked by `-L<path> -l<name>`
    (*e.g.*, `-L. -lfoo` to get `libfoo.a` from current directory)

Theory Applied to C (4/4)



- Effects of code changes:
  - If one `.c` file changes, just need to recreate one `.o` file, maybe a library, and re-link
  - If a `.h` file changes, may need to rebuild more
  - Many more possibilities!

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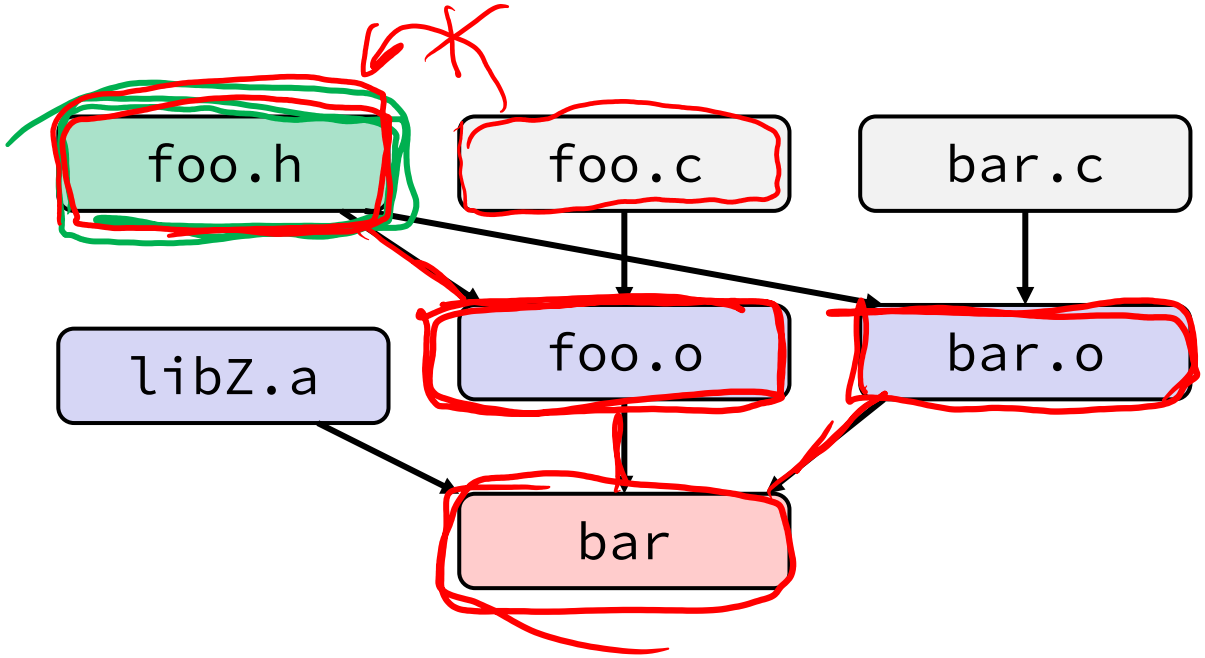
If foo.h changes, which files get re-built?

A. foo.o, bar.o
B. foo.o, bar.o, bar
C. foo.c, foo.o, bar
D. foo.c, foo.o
E. None of them



Lecture Outline

- Make and Build Tools
- **Makefile Basics**

make Basics

- A makefile contains a collection of **targets**:

```
Target-name: sources
← Tab → command
```

  - Colon after target name is *required*
  - Command lines must start with a **TAB**, NOT SPACES
  - Multiple commands for same target are executed *in order*
    - Can split commands over multiple lines by ending lines with '\'
  - If target produces an output file, the target name must be exactly the output's filename (this is how Make builds its dependency tree)

- Example:

```
foo.o: foo.c foo.h bar.h
	gcc -Wall -o foo.o -c foo.c
```

#include " "

don't build executable, build .o instead

NOT "here's a .c file"

-o means output name, NOT "build .o"

Using make

```
$ make -f <makefileName> target
```

- Defaults:
  - If no `-f` specified, use a file named `Makefile` in current dir
  - If no `target` specified, will use the first one in the file
  - Will interpret commands in your default shell
    - Set `SHELL` variable in makefile to ensure
- Target execution:
  - Check each source in the source list:
    - If the source is a target in the makefile, then process it recursively
    - If some source does not exist, then error
    - If any source is newer than the target (or target does not exist), run `command` (presumably to update the target)

"Phony" Targets

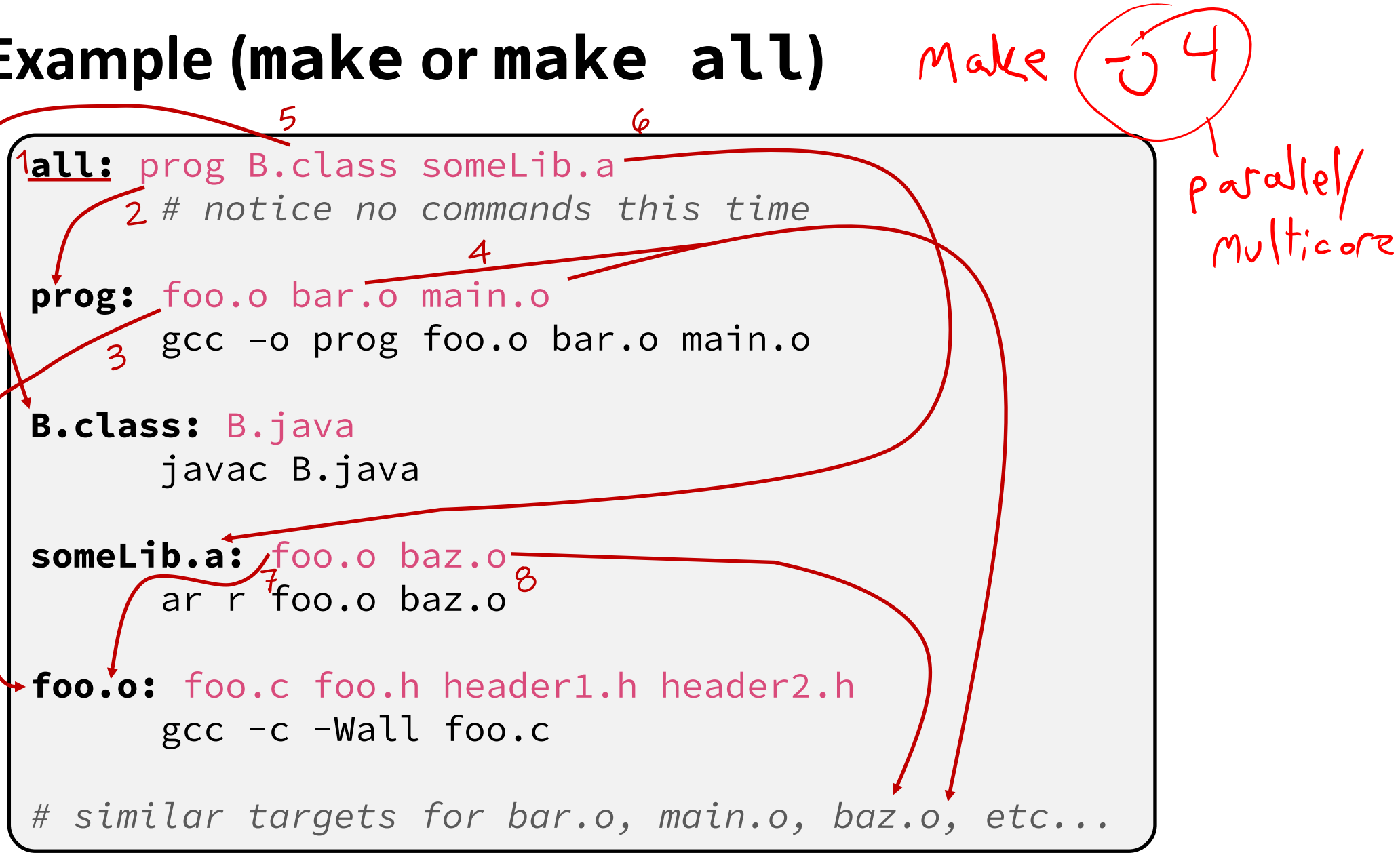
- A make target whose command does not create a file of the target's name (*i.e.*, a "recipe")
  - As long as target file doesn't exist, the command(s) will be executed because the target must be "remade"

- *e.g.*, target `clean` is a convention to remove generated files to "start over" from just the source

```
clean:
	rm foo.o bar.o baz.o widget *~
```

- *e.g.*, target `all` is a convention to build all "final products" in the makefile
  - Lists all of the "final products" as sources

"all" Example (make or make all)



make Variables

- You can define variables in a makefile:
  - All values are strings of text, no "types"
  - Variable names are case-sensitive and can't contain '**:**', '#', '=', or whitespace
- Example:

```
CC = gcc
CFLAGS = -Wall -std=c17
OBJFILES = foo.o bar.o baz.o
widget: $(OBJFILES)
        $(CC) $(CFLAGS) -o widget $(OBJFILES)
```

- Advantages:
  - Easy to change things (especially in multiple commands)
    - It's common to use variables to hold lists of filenames
  - Can also specify/overwrite variables on the command line: (*e.g.*, `make CC=clang CFLAGS=-g`)

Makefile Writing Tips

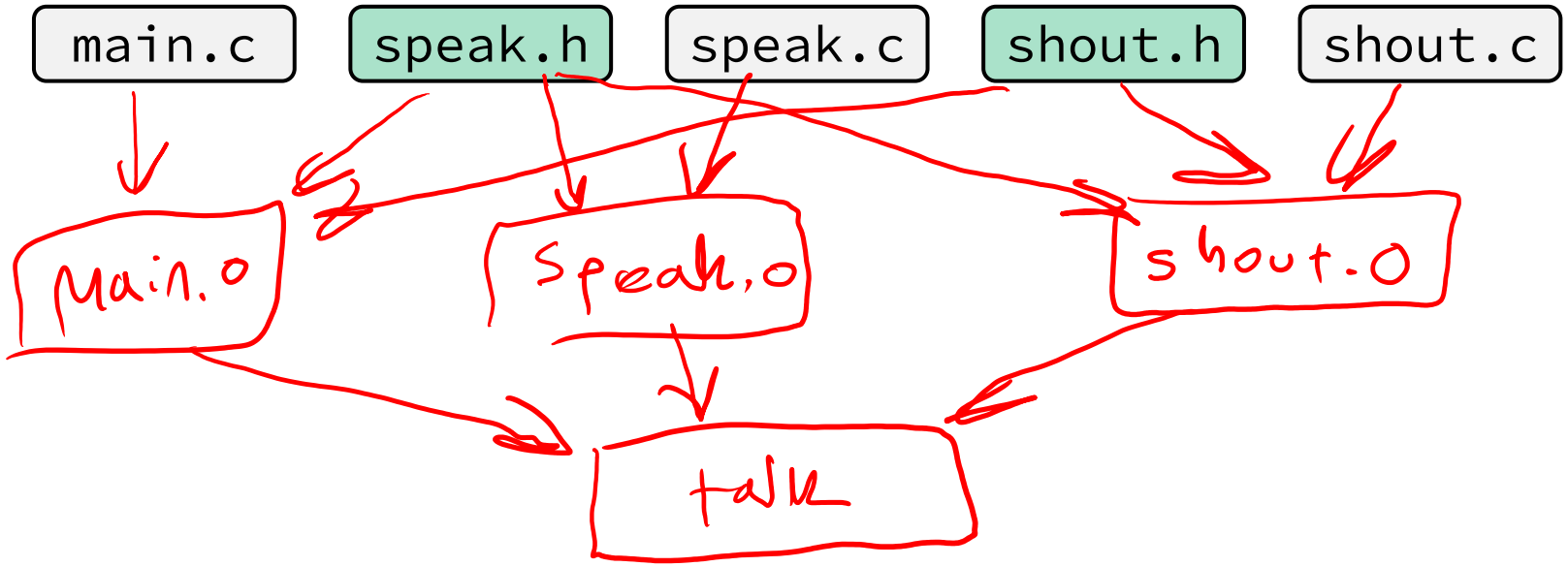
- *When creating a Makefile, first draw the dependencies!!!!*

- C Dependency Rules:
  - `.c` and `.h` files are never targets, only sources
  - Each `.c` file will be compiled into a corresponding `.o` file
    - Header files will be implicitly used via `#include`
  - Executables will typically be built from one or more `.o` file

- Good Conventions:
  - Include a `clean` rule
  - If you have more than one "final target," include an `all` rule
  - The first/top target should be your singular "final target" or `all`

Writing a Makefile Example: DAG

- "talk" program (find files on web with lecture slides)



main.c

```
#include "speak.h"
#include "shout.h"

int main(int argc, char** argv) {…
```

speak.c

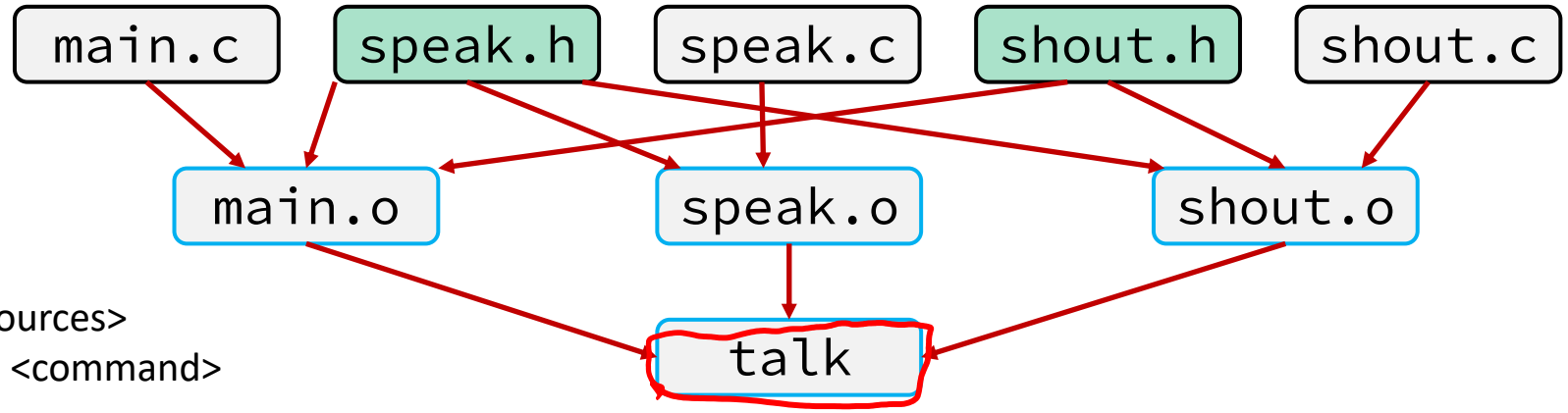
```
#include "speak.h"
...
```

shout.c

```
#include "speak.h"
#include "shout.h"
...
```

Writing a Makefile Example: Makefile

- "`talk`" program (find files on web with lecture slides)



<target>: <sources>
←tab character→ <command>

talk: main.o speak.o shout.o
←→ gcc $(CFLAGS) -o talk main.o speak.o shout.o

Revenge of the Funny Characters

- Special variables:
  - $@ for target name
  - $^ for all sources
  - $< for left-most source
  - Lots more! – see the documentation

- Examples:

```
# CC and CFLAGS defined above
widget: foo.o bar.o
        $(CC) $(CFLAGS) -o $@ $^

foo.o: foo.c foo.h bar.h
        $(CC) $(CFLAGS) -c $<
```

And more…

- There are a lot of "built-in" rules – see documentation
- There are "suffix" rules and "pattern" rules
  - Example:

```
%.class: %.java
	javac $<  # we need the $< here
```

a target for every .java file in root folder

- Remember that you can put *any* shell command – even whole scripts!
- You can repeat target names to add more dependencies
- Often this stuff is more useful for reading makefiles than writing your own (until some day…)

On the topic of compilation…

This is cool trivia, but totally unnecessary to know. Hopefully you enjoy it :)

- What's the best compilation message?

```
$ gcc -g - Wall -std=c11 -o msg not_a_function.c
not_a_function.c:1:6: warning: 'main' is usually a
                                function [-Wmain]
```

- C will let you do many things, many of which you should not do.
  - This is an example of something you should **NEVER** do.
- You can write a program that runs and prints!
  - Not portable though…

not_a_function.c

```
const int main[] = {
  -443987883, 440, 113408, -1922629632,
  4149, 2013696, 84869120, 15544,
  266023168, 1818576901, 1126199148, 857752915,
  169947955, 1936269379, 1701344288, 1936024096,
  -1878384268, 521126749, 1096237312, 1447165833
}
```

Credit to this blog:
http://jroweboy.github.io/c/asm/2015/01/26/when-is-main-not-a-function.html